FLOODPLAIN CONSTRUCTION BY RECENT, RAPID VERTICAL ACCRETION: WAIPAOA RIVER, NEW ZEALAND

BASIL GOMEZ[1*], DENNIS N. EDEN[2], DAVID H. PEACOCK[3] AND EDWARD J. PINKNEY[2]

[1]*Department of Geography and Geology, Indiana State University, Terre Haute, Indiana 47809, USA*
[2]*Manaaki Whenua – Landcare Research, Private Bag 11052, Palmerston North, New Zealand*
[3]*Engineering and Works Department, Gisborne District Council, PO Box 747, Gisborne, New Zealand*

Received 15 October 1996; 6 May 1977; 15 September 1997

ABSTRACT

The rate of vertical accretion (typically 14–18 mm h^{-1}) during eight floods in the Waipaoa River basin, with recurrence intervals of 5 to 60 years, was determined by relating the floodplain stratigraphy at McPhail's bend to the 1948–1995 flood history. Overbank deposits remaining after a flood that occurred in March 1996 suggest a rate of vertical accretion of 15 mm h^{-1}. By contrast, because the flow velocity across the floodplain was too high to permit deposition from suspension, during the record flood of March 1988 the rate of vertical accretion was only 6 mm h^{-1}. The sequence of deposition is highly discontinuous, and the rapid vertical accretion is a response to a late 19th to early 20th century phase of deforestation in the headwaters that probably initiated a far greater change in suspended sediment yield than in discharge. Cross-section surveys conducted since 1948 indicate that the high suspended sediment load of the Waipaoa River also promoted in-channel deposition, which effected a progressive reduction in bankfull channel width although, due to the overbank deposition, channel capacity remained constant. © 1998 John Wiley & Sons, Ltd.

Earth surf. process. landforms, **23,** 405–413 (1998)
KEY WORDS: channel capacity; deforestation; floodplain sedimentation; vertical accretion.

INTRODUCTION

Vertical accretion may be the dominant process of floodplain formation along stable, low-gradient, single-thread channels which transport a high proportion of their sediment load in suspension (Nanson and Croke, 1992). At times when the floodplain is inundated, suspended sediment is conveyed from the channel and across the floodplain by currents (which may also transport bedload) or by turbulent diffusion. Sediment accumulates on the floodplain if the concentration supplied from the channel exceeds the capacity of the floodplain flow to transport (cf. James, 1985; Pizzuto, 1987). Over time scales of 10^2 to 10^3 years, time-averaged estimates of rates of vertical accretion typically fall within the range 0·2 to 10 mm a^{-1} (Bridge and Leeder, 1979; Simm, 1995). But in most river basins floods have a limited duration and the frequency of overbank flooding is low, so that an estimate of the deposition rate which is an average for a period of years may bear little resemblance to the actual rate of deposition during an individual flood.

Floodplains are important sinks of sediment and pollutants (Meade, 1982; Marron, 1992; Mertes, 1994), and knowledge of sedimentation rates during individual floods is required not only to evaluate the extent to which a long-term average is representative of the rate of surface accretion during a single event, but also to test models of floodplain sedimentation and to improve understanding of floodplain development (Walling *et al.*, 1992). However, because low rates of deposition make it difficult to distinguish the contribution of individual floods to floodplain stratigraphy, rarely has it proved possible to obtain serial, event-based estimates of rates of vertical accretion. The availability of hydrologic records and planimetric and cross-section survey data provides a unique opportunity to determine event-based rates of vertical accretion on the Waipaoa River, New Zealand, floodplain over the last 50 years. We quantify the rate of vertical accretion on the floodplain bordering a 2·5 km long meander bend during eight recent intermediate- to high-magnitude floods with recurrence

* Correspondence to: B. Gomez
Contract/grant sponsor: New Zealand Foundation for Research, Science and Technology. Contract/grant number: 009306

CCC 0197-9337/98/050405–09 $17.50

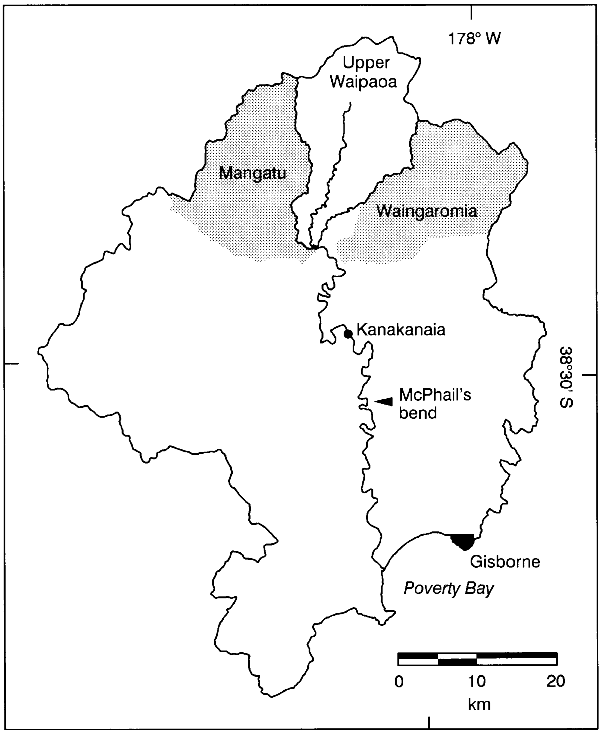

Figure 1. The greater Waipaoa River catchment, main stem and headwater subcatchments, and location of McPhail's bend and the gauging station at Kanakanaia

intervals of 5 to 60 years. This is accomplished by relating the floodplain stratigraphy to the 1948–1995 flood history. The rapid vertical accretion we document is a response to a late 19th to early 20th century phase of deforestation, and is conditioned by the Waipaoa River's high suspended sediment load (at discharges >200 $m^3 s^{-1}$ the suspended sediment concentration typically is >10 000 $mg\,l^{-1}$). Channel morphology should be affected by the hydrophysical changes in the catchment environment that deforestation engenders (cf. Schumm, 1977), and the planimetric and cross-section surveys also throw light on the behaviour of the Waipaoa River during the historic period.

STUDY AREA

The Waipaoa River drains into Poverty Bay and is located in the East Cape region of New Zealand's North Island (Figure 1). In its lower reaches the meandering single-thread channel is bordered by a well-defined floodplain. Both the channel and floodplain are aggrading. Maori settlements on the floodplain date from *c.* 700 years BP (Jones, 1988). However, extensive clearance of the native forest in the 205 km^2 catchment commenced in the late 1820s following the arrival of European settlers (Pullar, 1962). By 1880 most of the land in the catchment's lower reaches had been cleared and conversion to pasture in the headwaters was underway. The latter phase of deforestation was completed by 1920 and only 2·5 per cent of the catchment is now under primary forest. Reforestation of portions of the headwaters with exotic species, such as *Pinus radiata,* began in 1960 and commercial timber harvesting commenced in 1990.

The late 19th to early 20th century phase of deforestation caused particularly intense erosion of the incoherent rocks in the Mangatu, Upper Waipaoa and Waingaromia subcatchments (O'Byrne, 1967). For example, the mean annual suspended sediment yield of the Waingaromia and Mangatu subcatchments is 17 340 and 7045 $t\,km^{-2}\,a^{-1}$ (Griffiths, 1982). The impact of this erosion on headwater streams has been well documented (e.g. Allsop, 1973; Gage and Black, 1979). At Kanakanaia, the river drains an area of 1582 km^2 and the mean

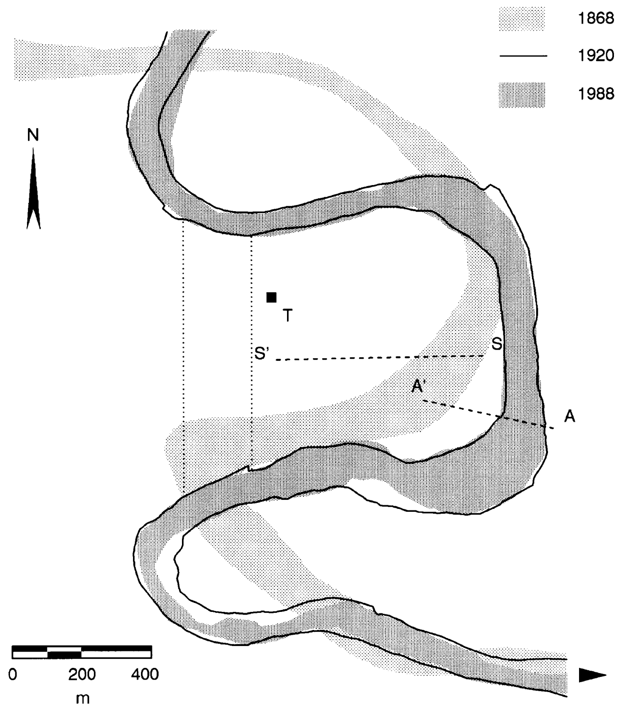

Figure 2. Planform changes in the geometry of McPhail's bend, 1868–1988. A′–A and S′–S denote endpoints of channel and floodplain cross-sections (Figures 3 and 4). The dotted lines delimit the floodway, the solid square shows the location of the 9·7 m core, 'T' the location of the trench, and the arrow indicates the direction of flow

annual suspended sediment load is of the order of $9{\cdot}0\times10^6$ t (Griffiths, 1982; Walpole, 1994). We estimate that *c.* 5 per cent of the total sediment load of the Waipaoa River, at Kanakanaia, is transported as bedload.

Discharge and suspended sediment records are available for the period from 1960. The 1948 flood was rated, and the annual series of flood peaks extends back to 1938. Estimates of the peak discharge of several large floods that occurred in the early part of this century have also been made (B. G. Walpole, personal communication).

McPhail's bend

We focus on a $0{\cdot}5\,km^2$ area of the Waipaoa River floodplain, bounded by McPhail's bend, that is located between 31 and 33·5 km upriver from the mouth (Figure 2). This reach of the Waipaoa River was first surveyed in 1868, a second planimetric survey was undertaken in 1920, and an orthophoto map assembled in 1988. Channel cross-sections at three locations around McPhail's bend have been resurveyed periodically since 1948 (Figure 3). Floodplain transects across the axis of the bend were surveyed in 1979 and resurveyed in 1990 (Figure 4).

Unlike riparian land further downriver, McPhail's bend has remained under pasture throughout the historic period. In the vicinity of the bend the natural floodplain is bordered by low hills, and its width (1·2 km) does not vary appreciably either up- or downriver. The local floodplain slope is 0·00011. Prior to 1948, 1 m high stopbanks (artificial levees) were raised around the perimeter of the bend. These stopbanks fell into disrepair following construction of a floodway, bordered by 2 m high stopbanks, across the neck of the bend in 1953. The effect of the floodway has been to decrease the volume of flow across the bend and reduce the width of the active floodplain to 0·7 km. On the basis of the measured discharge, all of the flood events we recognize in the stratigraphic record overtopped the 1 m stopbanks.

The mean annual flood at Kanakanaia is $1070\,m^3\,s^{-1}$, but a discharge $>1700\,m^3\,s^{-1}$ (recurrence interval *c.* 4 years annual maximum series) currently is required before water encroaches onto the floodplain at McPhail's bend (Figure 5). The river responds rapidly to the onset and cessation of precipitation, and the low (<1 m) relief of the floodplain obviates hysteresis in the relation between channel discharge and volume of inundation.

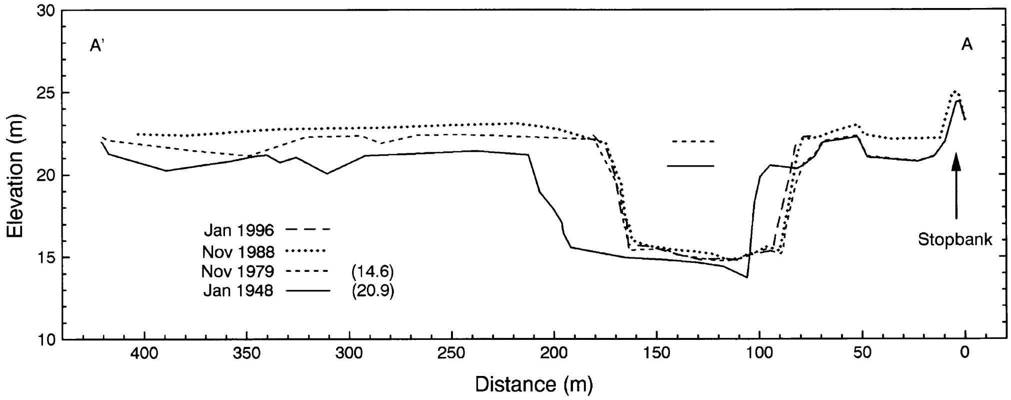

Figure 3. Change in channel cross-section geometry January 1948 to January 1996. Horizontal lines indicate the bankfull capacity in the specified year, and the figures in parentheses the width–depth ratio. The cross-section location is shown in Figure 2

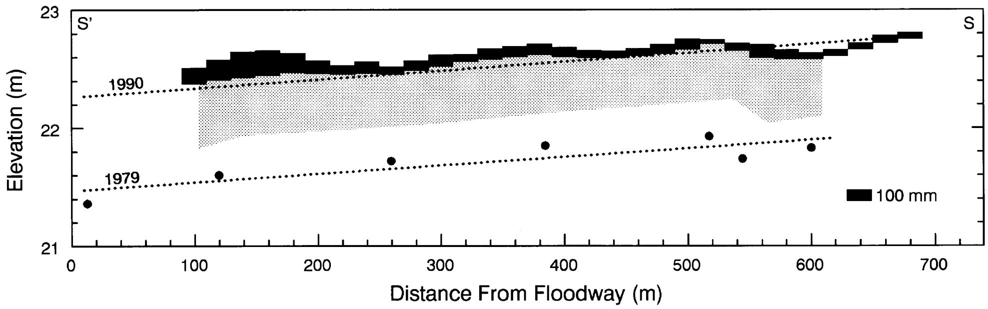

Figure 4. Average change in floodplain elevation, 1979–1990, along the axis of McPhail's bend (shown by regression lines; note that data points delimiting the 1990 surface are not plotted), and thickness of March and September 1988 (stippled) and March 1996 (solid bars) flood deposits. The cross-section location is shown in Figure 2

Active overbank flow occurs across the bend at discharges >1800 $m^3 s^{-1}$ and advective transport, not diffusion, is the dominant process involved in the transfer of suspended sediment from the channel to the floodplain. In the period 1948–1995, 12 flood events with a peak discharge >1800 $m^3 s^{-1}$ are known to have inundated the bend. These include the three largest floods on record, which each had a peak discharge >3500 $m^3 s^{-1}$, and 12 of the 19 largest floods documented this century (Figure 5). A flood with a recurrence interval of *c.* 8·5 years also inundated the bend in March 1996. At a discharge of 1826 $m^3 s^{-1}$ (on the waxing limb of the flood hydrograph) depth-integrated samples collected at several points across the channel yielded a suspended sediment concentration of 30 690 $mg\,l^{-1}$. However, at present, we have no knowledge of the relation that suspended sediment concentration has to discharge during this, or any other, flood event.

Methodology for reconstructing floodplain stratigraphy

To reconstruct the floodplain stratigraphy we utilized information derived from two cores and a trench. A 9·7 m long, 75 mm diameter core was obtained near the locus of the 1868 bend (Figure 2), and a shorter (3·2 m) core was taken from a nearby site on the floodplain adjacent to a 5·8 m deep trench. The bulk of the floodplain alluvium is <63 μm in diameter (D_{50}<10 μm), and unit thicknesses were corrected for core compaction; however, there was no appreciable difference in bulk density between the top and bottom of the 9·7 m core. Short (<1 m deep) cores were also obtained from 37 other sites across the floodplain to ascertain the thickness and composition of sediments deposited during floods that occurred in March and September 1988, and the thickness of the April 1996 flood deposits was determined from 30 shallow pits dug at regularly spaced intervals along the line of the floodplain transect. Particle size analyses were performed on sediment samples taken from

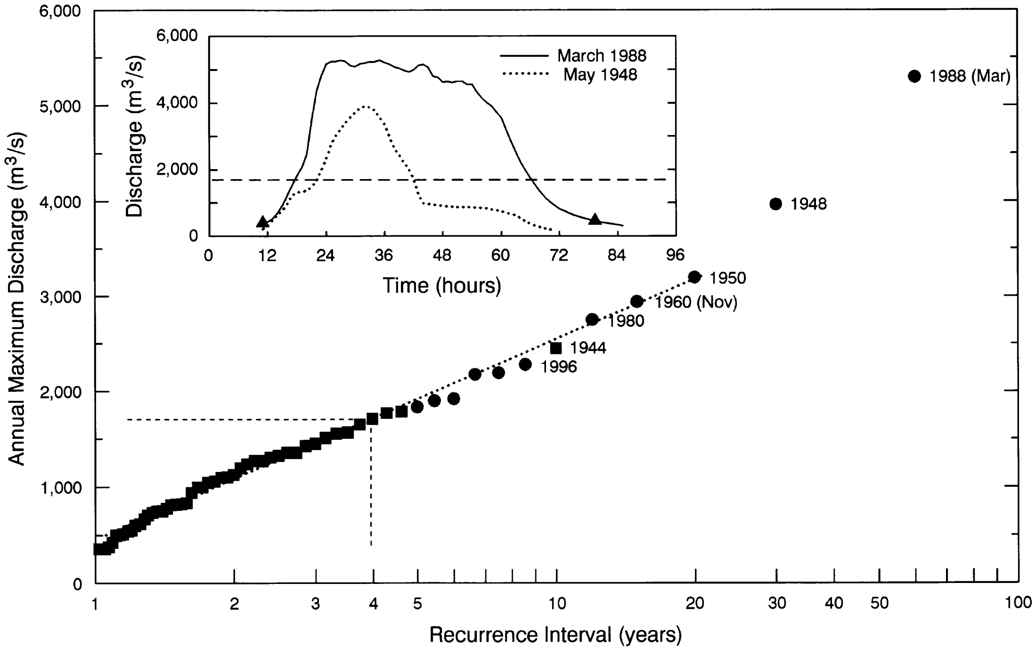

Figure 5. Recurrence interval of annual maximum discharge (measured and estimated flood events), Waipaoa River, at Kanakania for the period 1938 to 1996. Note that the December 1960 and September 1988 floods do not appear on this plot, but for return periods >10 years there are negligible differences between the recurrence intervals for floods derived from the annual maximum and partial duration flood series. Solid dots indicate floods that overtopped McPhail's bend in the period 1948 to 1996, the dashed lines indicate the magnitude of the flood required to overtop the bend, and the change in the slope of the flood frequency curve ($r^2 = 0{\cdot}99$) at a recurrence interval of *c.* 20 years is probably a function of the high rainfall intensities experienced during the largest storms. Inset: comparison of hydrographs for the first- and second-ranked May 1948 and March 1988 floods. Solid triangles show when depth-integrated suspended sediment samples were obtained during the 1988 flood. The dashed line indicates the discharge at which McPhail's bend is overtopped

the 9·7 m core. There was no evidence of any erosional contacts in the stratigraphic record, but we were able to differentiate the massively bedded flood deposits on the basis of texture and colour.

We derived a composite stratigraphy on the basis of the record provided by the 9·7 m core, supplemented by information derived from the 3·2 m core and the trench (Figure 6). We also used ^{137}Cs dating to help constrain the recent flood history. In the 9·7 m core ^{137}Cs first appeared at a depth of 1·335 m which equates with a depth of *c.* 1·35 m in the composite stratigraphy. These data are not discussed further because here we refer only to the composite stratigraphy. On the basis of the composite stratigraphy, evidence of seven recent floods is preserved in the stratigraphic record, by horizontally bedded, fining-upward sequences of overbank deposits that are between 0·1 and 0·3 m thick (Figure 6). We estimated the average rate of vertical accretion (mm h^{-1}) for six floods on the basis of the length of time the discharge at Kanakanaia was >1700 $m^3 s^{-1}$. We also determined a composite rate of vertical accretion for two floods that occurred in the early 1980s, which could not be differentiated on the basis of the stratigraphic evidence. Our field measurements indicated that the March 1996 flood contributed *c.* 100 mm of additional sediment to the floodplain (Figures 4 and 6).

We assessed the precision of the composite stratigraphy by comparing the aggregate thickness of the March 1988, September 1988, April 1982 and December 1980 flood deposits and the measured change in the elevation of the floodplain surface, during the period 1979 to 1990. During this period the floodplain elevation increased by an average of *c.* 0·8 m (Figure 4), as compared with the *c.* 0·7 m increase implied by the composite stratigraphy (Figure 6). The aggregate thickness of the March and September 1988 flood deposits, as determined from the short cores, varied between 0·4 and 0·7 m, which compares with the *c.* 0·4 m thickness implied by the composite stratigraphy. Thus, deposition along the axis of the bend appears to be slightly under-represented by the composite stratigraphy. However, topographic surveys indicate that the amount of vertical

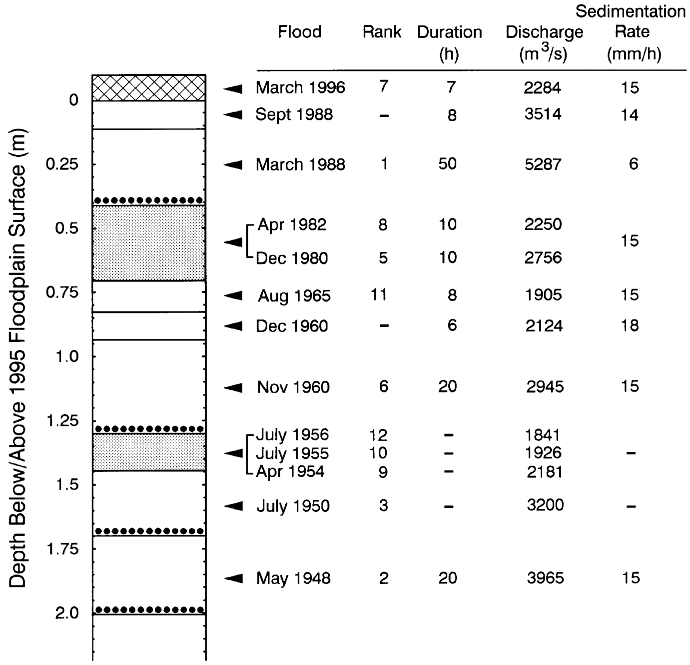

Figure 6. Thickness of overbank deposits on McPhail's bend and rate of vertical accretion during specified floods in the period 1948–1988. Rank order based on annual maximum series (Figure 5). Solid dots indicate that a basal sand unit is present in the flood deposits. Stipple signifies that deposits could not be assigned to individual floods. The thickness of the March 1996 flood deposits (cross-hatched) is based on the average depth of sediment along transect S′–S (Figure 3)

accretion on McPhail's bend is comparable with the depth of sediment deposited at other locations on the floodplain between 1979 and 1990.

VERTICAL ACCRETION

The duration of most floods was short (6–20 h), but rates of vertical accretion on the floodplain at McPhail's bend were high (typically 14–18 mm h^{-1}) and appear, on the basis of our calculations, to be remarkably consistent from event to event. By comparison, the rate of vertical accretion during the record flood of March 1988 was low (6 mm h^{-1}). We argue that the low rate reflects the relation of particle settling velocity to flow velocity across the floodplain and was conditioned by the flood hydrology, not sediment exhaustion; 15 h prior to the flood peak the suspended sediment concentration at Kanakanaia was 21 800 mg l^{-1} and 53 h after the flood peak it was 16 880 mg l^{-1}. The rate of rise and fall in stage during the March 1988 event was comparable with that experienced during other large floods in the catchment, but the period of high flow was unusually protracted (Figure 5 inset). Discharges >3000 $m^3 s^{-1}$ were sustained for 41 h, compared with a period of 12 h during the May 1948 flood. We used the mathematical model LATIS, as modified by Hall (1983), to compute the maximum depth of water (2·2–2·5 m) and corresponding flow velocity (0·25–0·55 m s^{-1}) across the bend during the March 1988 flood. At these velocities silt- and clay-sized particles remain in suspension, and the extended period of high flow during the March 1988 flood is represented by a well-sorted, 0·02 to 0·46 m thick, gravel–sand unit (D_{50} = 0·7–2·5 mm). This sediment was probably transported across the floodplain as bedload, and there is no decline in median diameter away from the channel. The remainder of the March 1988 flood deposit consists of a comparatively thin (0·03–0·18 m), fining-upward, sand–silt–clay unit that presumably was deposited from suspension on the falling limb of the flood hydrograph.

A well-sorted sand unit was also present at the base of the 1948, 1950 and 1960 flood deposits. Although the growth of spring grass may have enhanced resistance to flow on the floodplain, a similar unit probably was prevented from accumulating during the September 1988 flood (which was larger than either the 1950 or 1960

events) because the sand-sized bed material load was confined within the channel by the ever-increasing disparity in elevation between the bed of the channel and the floodplain. Cross-section surveys indicate that for the period 1948–1994 the local rate of aggradation in the channel was 18 mm a^{-1}. Over a comparable time period (1948–1995) the rate of vertical accretion on the floodplain was 43 mm a^{-1}. This is a similar magnitude to the rate that probably prevailed during the 1942 to 1960 period of floodplain reconstruction on the Cimarron River, Kansas (Schumm and Lichty, 1963), and on the floodplain of tributary streams in the Galena River basin, Wisconsin, in the period following mid-19th and early 20th century mining disturbances (Knox, 1987).

On the basis of the ever-increasing disparity in the channel and floodplain elevations, it is tempting to conclude that the frequency of overbank flooding and the incremental rate of vertical accretion on the floodplain may have declined with time. However, although the discharge record is too short to determine whether or not the flow frequency has changed, there was no change in channel capacity during the period 1949 to 1996 (Figure 3). For the (12 and 36 year) periods May 1948 to November 1960 and December 1960 to March 1996, the average rate of accumulation of successive 1·07 and 0·935 m increments of sediment on the floodplain was 89 and 26 mm a^{-1}, respectively. But the depositional sequence is highly discontinuous, and the rate of deposition during individual events remained remarkably constant (Figure 6). Thus, perspectives on the average rate of vertical accretion, of necessity, must be tempered by (lack of) knowledge of the continuum of deposition and event duration (during the period May 1948 to March 1996, about 2 m of vertical accretion was accomplished in rather less than 0·1 per cent of the available time).

CHANNEL ADJUSTMENTS

A photograph taken in 1895 shows a wide, low-angle point bar at the apex of McPhail's bend, but a narrower, deeper channel has evolved in the intervening period as a consequence of suspended sediment deposition on the point bar. The last vestiges of this process are evident in the change in cross-section geometry experienced between 1948 and 1979 (Figure 3). Although channel capacity (600 m^2) remained essentially constant throughout this period, the width–depth ratio of the 1979 channel is 30 per cent less than the width–depth ratio of the 1948 channel. The cross-section geometry has remained stable since 1979, despite the March 1988 flood. These changes are representative of changes that have occurred throughout the river's lower reaches, and are documented at numerous other surveyed cross-sections.

The configuration of McPhail's bend changed substantially in the period between 1868 and 1920 (Figure 2), but the planform geometry has not changed appreciably since 1920, and between 1948 and 1996 the bend migrated laterally by ≤20 m (Figure 3). Rip-rap protection and willow planting may have helped to constrain the planform geometry since the beginning of the 20th century, as do the low hills bordering the floodplain. Between 1948 and 1994 the 2·5 km reach around the bend aggraded by 0·5 m and the local channel slope increased by 14·5 per cent, from 0·00076 to 0·00087. The bed material within this reach has a D_{50} of 2·7 mm and a Trask sorting coefficient of 2·2. Gravel from the base of the 9·7 m core, which may be representative of the presettlement bed material, has a similar D_{50} (2·8 mm) and a sorting coefficient of 5·1. The change in sorting reflects a 50 per cent reduction in the size of material in the 50th to the 100th percentiles; for example, the D_{95} of the contemporary bed material is 16·8 mm, compared to 34·2 mm for the gravel at the base of the core. The contemporary bank material has a D_{50} of 84 µm, and 31 per cent of the sediment is finer than 63 µm.

We suspect that following the headwater clearances in the Waipaoa River basin the change in suspended sediment yield was of far greater magnitude than the change in flow regime. Mutual adjustments in the width and depth of a channel are highly dependent on sediment characteristics (Schumm, 1960; Miller, 1984), but we have yet to determine whether or not the metamorphosis was assisted by a corresponding increase in bank material cohesion. However, the response of the Waipaoa River to anthropogenically induced disturbance in the catchment environment is similar to that documented by workers in other regions. For example, Jacobson and Coleman (1986) found evidence of progressive channel deepening preserved in the stratigraphic record, although they inferred that the channels of Piedmont rivers in Maryland had also widened in the period following European settlement. Knox (1977) argued that the transportation and deposition of suspended load sediments were the dominant forces in the historical metamorphosis of the bankfull channel dimensions in the

lower reaches of the Platte River basin, Wisconsin, where, although channel capacities are similar, most modern channels are narrower and deeper than their presettlement counterparts. Richards (1979) also emphasized the dominant role played by the change in the suspended sediment load compared to the change in discharge as the cross-section geometry of Cornish rivers adjusted to the abnormally high suspended sediment loads imposed by kaolin mining; the pollution effected a substantial reduction in the width–depth ratio while the channel capacity remained unaltered.

CONCLUSIONS

Serial, event-based estimates of the rate of overbank sediment accumulation on floodplains are rare. It is also novel to be able to document the response of both the floodplain and channel to anthropogenically induced change in the catchment environment. This study offers an integrated perspective on the Waipaoa River's response to a late 19th to early 20th century phase of deforestation in the headwaters, and its attainment of a new metastable equilibrium configuration.

The stratigraphy of the 0·5 km^2 area of the floodplain bordered by the 2·5 km long McPhail's bend indicates that, for the period 1948 to 1995, the rate of vertical accretion in most floods was 14 to 18 mm h^{-1} (Figure 6). The rate during a flood in March 1996 was 15 mm h^{-1}. However, because flow velocities across the floodplain were too high to permit deposition from suspension, the record flood of March 1988 was characterized by a comparatively low rate of vertical accretion (6 mm h^{-1}).

Vertical accretion on the floodplain, which was highly discontinuous, was accompanied by in-channel deposition which profoundly altered the shape of the channel cross-section. The in-channel deposition, in concert with vertical accretion on the floodplain, helped to stabilize the planform geometry and, while the channel capacity remained constant, effected a progressive reduction in the bankfull channel width and an increase in depth.

ACKNOWLEDGEMENTS

This paper is a contribution to Manaaki Whenua – Landcare Research's Waipaoa Catchment Study, funded by the New Zealand Foundation for Research, Science and Technology (Contract No. 009306). We thank Bruce Walpole, Donna Rowan, Brenda Rosser and Bernard Barry for their assistance with this study. Noel Trustrum coordinated our efforts, and we are especially indebted to Brian Currie and the surveyors and engineers who undertook the mapping and instigated the monitoring programmes. Leal Mertes was a perceptive and helpful reviewer.

REFERENCES

Allsop, F. 1973. *The Story of Mantagu Forest*, Government Printer, Wellington, New Zealand, 100 pp.

Bridge, J. S. and Leeder, M. R. 1979. 'A simulation model of alluvial stratigraphy', *Sedimentology*, **26**, 617–644.

Gage, M. and Black, R. D. 1979. *Slope stability and geological investigations at Mantagu State Forest*, New Zealand Forest Service, Forest Research Institute Technical Paper, **66**, 47 pp.

Griffiths, G. A. 1982. 'Spatial and temporal variability in suspended sediment yields of North Island basins, New Zealand', *Water Resources Bulletin*, **18**, 575–584.

Hall, G. W. 1983. *LATIS Revision 1.0, Channel Hydraulics*, Gisborne, East Cape Catchment Board Computer Systems Documentation, 40 pp.

Jacobson, R. B. and Coleman, D. J. 1986. 'Stratigraphy and recent evolution of Maryland piedmont floodplains', *American Journal of Science*, **286**, 617–637.

James, S. C. 1985. 'Sediment transfer to overbank sections', *Journal of Hydraulic Research*, **23**, 435–452.

Jones, K. L. 1988. 'Horticulture and settlement chronology of the Waipaoa River catchment, East coast, North Island, New Zealand', *New Zealand Journal of Archaeology*, **10**, 19–51.

Knox, J. C. 1977. 'Human impacts on Wisconsin stream channels', *Annals of the Association of American Geographers*, **67**, 323–342.

Knox, J. C. 1987. 'Historical valley floor sedimentation in the Upper Mississippi Valley', *Annals of the Association of American Geographers*, **67**, 224–244.

Marron, D. C. 1992. 'Floodplain storage of mine tailings in the Belle Fourche River system: a sediment budget approach', *Earth Surface Processes and Landforms*, **17**, 675–685.

Meade, R. H. 1982. 'Sources, sinks, and storage of river sediment in the Atlantic drainage of the United States', *Journal of Geology*, **90**, 235–252.

Mertes, L. A. K. 1994. ‘Rates of flood-plain sedimentation on the central Amazon River’, *Geology*, **22**, 171–174.
Miller, T. K. 1984. ‘A system model of stream-channel shape and size’, *Geological Society of America Bulletin*, **95**, 237–241.
Nanson, G. C. and Croke, J. C. 1992. ‘A genetic classification of floodplains’, *Geomorphology*, **4**, 459–486.
O’Byrne, T. N. 1967. ‘A correlation of rock types with soils, topography and erosion in the Gisborne – East Cape region’, *New Zealand Journal of Geology and Geophysics*, **10**, 217–231.
Pizzuto, J. E. 1987. ‘Sediment diffusion during overbank flows’, *Sedimentology*, **34**, 301–317.
Pullar, W. A. 1962. ‘Soils and agriculture of Gisborne Plains’, *New Zealand Department of Scientific and Industrial Research Soil Bureau Bulletin*, **20**, 92 pp.
Richards, K. S. 1979. ‘Channel adjustment to sediment pollution by the china clay industry in Cornwall, England, in Rhodes, D. D. and Williams, G. P. (Eds), *Adjustments of the Fluvial System*, Kendall/Hunt, Dubuque, 309–331.
Schumm, S. A. 1960. *The shape of alluvial channels in relation to sediment type*, US Geological Survey Professional Paper **352B**, 17–30.
Schumm, S. A. 1977. *The Fluvial System*, John Wiley and Sons, New York, 338 pp.
Schumm, S. A. and Lichty, R. W. 1963. *Channel-widening and flood-plain construction along Cimarron River in southwestern Kansas*, US Geological Survey Professional Paper **352-D**, 71–88.
Simm, D. J. 1995. ‘The rates and patterns of overbank deposition on a lowland floodplain’, in Foster, I. D. L., Gurnell, A. M. and Webb, B. W. (Eds), *Sediment and Water Quality in River Catchments*, John Wiley and Sons, Chichester, 247–264.
Walling, D. E., Quine, T. A. and He, Q. 1992. ‘Investigation of contemporary rates of floodplain sedimentation’, in Carling, A. and Petts, G. E. (Eds), *Lowland Floodplain Rivers: Geomorphological Perspectives*, John Wiley & Sons, New York, 165–184.
Walpole, B. G. 1994. *East Coast Water Resources Report: Historical – 1993*, Gisborne District Council, 99 pp.

